Observation of Optical transients and Search for PeV-EeV Tau Neutrinos with Ashra-I

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Ashra @ Mauna Loa
Contents

- Ashra-I detector & DAQ
- Analyses:
  Optical transients
  PeV-EeV tau neutrinos
- Prospects:
  Observation 4: Galactic Center γ
  NTA

Analysis of Ashra-I commissioning phase data are presented. Performance of the system was established. We are ready for observation 4 and for NTA
Ashra-1 Light Collector

- **Optics:**
  - Modified Baker-Nunn

- **Components:**
  - **Correcting lens** (1.0~1.2mφ) with 3 acrylic cut plates
  - **Spherical mirror** (2.2mφ) with 7 curved glass plates on adjustable tables.
  - **Photoelectric lens IT** (0.5mφ) on focal sphere suspended with Stewart platform mechanism
  - **Mount structure** with steel channels for easy assembly

=> a few arcmin. resolution over 42deg FOV
=> affordably cost-effective
Ashra-1 Pipeline Trigger & Readout

Same Fine Image to Multiple Triggers

Photo-electric Image Pipeline (PIP)

Multi-Messenger Approach with One Detector System

High Pixelation w/ CMOS → Fine Resolution

demonstrated

Optical 4s

BG 200ns

CR 200ns

1st imaging air-shower with self-trigger
Integrated observational time in 2008-2013

Optical image data for Flash search: 5783 hours

Cherenkov image data for $\nu_T$ search: 1884 hours
GRB Optical Flash Search (GRB081203A)


Alert within FOV

Swift BAT time $t_0 = 13:57:11$ UT

VHE neutrino obs. $t_0 - 2.83\text{hr} ightarrow t_0 + 2.13\text{hr}$

Multi-wavelength + Ashra Ontime / Precursor monitor \Rightarrow Restrict models

Each 6s-period, plot the limits \Rightarrow circular #8632

T0-100s

3A Significance Map at T0-100 sec

T0

GRB081203A Significance Map at T0

T0+100s

6s-Exposure images \Rightarrow SNR-map

SNR histo around GRB

6s-Exposure images \Rightarrow SNR-map

GRB081203A Significance Map at T0+100 sec

GRB081203A Optical Observations
- PeV-EeV Neutrino search method -

Air Shower: Excellent Tool of Astronomy

$\nu_\tau$ Simulation: $E_\nu = 10^{18.0}$ eV, $E_\tau = 10^{17.2}$ eV, Event# 000069

27.6 PeV $\pi^0 \Rightarrow 3790$ p.e.
29.0 PeV $\pi^0 \Rightarrow 4145$ p.e.
48.3 PeV $\pi^- \Rightarrow 3703$ p.e.

TRIGGERED! ($N_{\text{Trig}} = 2$)

$(\theta_{\text{zenith}}, \phi_{\text{azimuth}}) = (91.73, 16.15)\ \text{deg}$

$N_{\text{pe}}: 11639.0$, $R_p: 372.7$m, (Width,Length) = (0.04, 0.15) deg

Earth Skimming Tau Neutrinos

Asaoka & Sasaki, Astropart. Phys. 41 (2013) 7-16

Tau induced Air Shower blows out
AS Cherenkov Images taken by Ashra-1

Obs03 (2012-2013):

Trigger Pixels for CR:
4 trig. pixels
1884 hrs
Alt: 26.34° ± 1.29°
Azi: 21.99° ± 1.29°
Fine Pix: 0.05°/pix

Trigger Pixels for Taus
58 pixels
1950 hrs

Alt: 11.71°
Azi: 21.99°
CR Observed Energy Spectrum

Effective aperture

- Improved for Obs.4
- Obs.3

Obs03 events
MC normalization by CR flux.

- 824 events (1884 hrs)
  Used for ES-ντ search

Detectability of τ shower confirmed

Source of Systematics | Error [%]
--- | ---
Trigger Threshold | 19
Atmosphere & Optics | 21
DAQ Efficiency | 6.3
Weather Condition | 6.4
Sensitivity Total | 30
Fine Image Gain | 30

Become negligible due to LED flasher calibration
Comparison of ES Tau Neutrino Flux Limits

Null result (1863 hrs) of ES-$\nu_\tau$ search

- MAGIC 30hr
- MAGIC 300hr
- Auger Downward 2yr
- Auger ES 3.5yr
- Ashra-1 1863hr (1.2yr)
- IceCube40 375.5days
- LUNASKA ~1000km²days
- Model CenA flare
- Model CenA core

- Ashra-1 Obs03 best PS sensitivity for ES-$\nu_\tau$

References:
- Auger (2012).
  GI-Astro-Ph.HE, 1–21.
  Astropart.Phys.102, 77-88.
- IceCube (2011).
  PRD 78(2), 1–5.
- Kachelrieß (2009).
  New Journal of Physics, 11.
Next step:

Target Example of VHEPA: Galactic Center

Diffuse emission from the GC without a perceivable cutoff

- To clearly fix it, the detector is required to:
  1) $\gamma$-ray/ν multiple observation
  2) 0.1 deg. resolution like IACT
  3) good sensitivity for $E_\gamma > 50$ TeV

$\Rightarrow$ Ashra/NTA meets.

Point source emission with a 10 TeV cut-off

HESS GC observation 227 hours / 10 years

$\Rightarrow$ Need monitor obs. with wider FOV IACT.

HESS PSF

Nature 531 (2016)
Simulated southern sky at the Ashra-1 Mauna Loa site at 0:00 on June 23, 2019. The star mark indicates the location of the galactic center (GC). The track of GC (arc) and the FOV of the rearranged Ashra-1 light collectors (circles) are also shown.
Advantage of Ashra-1/NTA imaging GC $\gamma$

**Ashra-1/NTA**

Effective detection area $S$ :

$S$ increase as $\theta$ due to far Cherenkov

Cherenkov light: small attenuation

$\Rightarrow$ more advantage for higher Energy

**Ground 2D particle array**

$S = S_0 \cos \theta$

Shower particle electron:

severe attenuation

$\Rightarrow$ Only effective $\theta < 45^\circ$

$\Rightarrow$ Duty cycle < 50%

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**GC survey** (HESS: 227hr/10yr)

$T = 1150 \sim 1900$ hr/yr ($\theta = 48 \sim 90^\circ$)

$S = 0.3 \text{ km}^2/1\text{unit} @ 10 \text{ TeV}$ ($\theta = 70^\circ$)

$12 \text{ km}^2/1\text{unit} @ 1 \text{ PeV}$ ($\theta = 70^\circ$)

$T = 2300 \text{ hr/yr}$ ($\theta < 45^\circ$) @S. lat.16 deg

$S < 0.2 \text{ km}^2$ (500m 2D array)
Next next step: NTA summit array
detection of ν / γ-ray / CR

- τ decay length: \( L_\tau \sim 50\text{m} (E_\tau/\text{PeV}) \)
  \( \Rightarrow \) can watch nearer \( 1 \sim 10\text{PeV} \) AS max
- lower detection E threshold
- better observation efficiency @3000m asl
NTA diffuse $\nu$ sensitivity: with Cherenkov & fluorescence light

NTA most sensitive for 1PeV-100PeV $\nu$

Clear test:
IceCube PeV $\nu$ extension
Cosmogenic $\nu$

Far ES tau neutrino
Cherenkov observation

Near ES tau neutrino
fluorescence observation

Thanks to look-out layout

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<th>aper.</th>
<th>height</th>
<th>Fov</th>
<th>Resol.</th>
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<tbody>
<tr>
<td>NTA</td>
<td>10 m²</td>
<td>3 km</td>
<td>360° x 30°</td>
<td>0.125°</td>
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Conclusions

- Precursor search in 84 GRB candidates from 5783 hours optical image data is in progress.
- PeV-EeV cosmic-ray spectrum was successfully obtained from 1884 hours of Cherenkov image data.
- PeV-EeV tau neutrino point source flux is limited to be:
  \[ E_{\nu_{\tau}}^2 \cdot \phi(E_{\nu_{\tau}}) < 3.2 \times 10^{-7} \text{GeV cm}^{-2} \text{s}^{-1} \]
  from 1863 hours of Cherenkov image data toward Mauna Kea and the earth crust around it.
- Successfully demonstrated Ashra unique features.
- Observation 4: Dedicated observation for Galactic center \( \gamma \)-rays is proposed using 6 LCs, which allows putting the Galactic center into FOV for more than 1000 hours/yr.
- NTA to look out at the summit: enjoys huge acceptance for far Ceren. ES-\( \nu_{\tau} \) events. => the best \( \nu \) sensitivity in PeV-EeV region with IACT reso.

Please join us!